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Overview of Piezoelectric Actuator Displacement Measurements Utilizing a MTI-2100 Fotonic Sensor

by Asha Hall and Mark Bundy

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Asha Hall and Mark Bundy
Vehicle Technology Directorate, ARL

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14. ABSTRACT
The MTI-2100 is a measurement system that provides for non contact precise measurement of the position, the displacement (micro-positioning), and the vibration of an object in planar motion. By using fiber optic technology, these measurements provide assistance to thoroughly understanding the structural dynamics of a planar actuating object. This report describes the operational principles of the MTI-2100 Fotonic™ Sensor measurement system. To illustrate how it works in practice the measurement system was used on a $Pb(Zr_{0.55}Ti_{0.45})O_3$ (PZT) bimorph driven flapping wing to measure flapping amplitude and frequencies.

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1. Introduction to MTI Instrumentation

Lead-based piezoelectric actuators can displace from sub-nanometer to mm-range at high frequencies (depending on their form factor), because the motion is a result of an applied electric potential effecting solid-state crystal structure. These devices do not have rotating or sliding parts to cause friction and, therefore, dissipate virtually no power. The Adaptable Structures Team of the U. S. Army Research Laboratory (ARL) Vehicle Technology Directorate (VTD) under the Mechanics Division is developing enabling technologies for autonomous micro air vehicles (MAVs) that incorporate biomimetic flight utilizing a piezoelectric actuator. This design utilizes a layered $Pb(Zr_{0.55}Ti_{0.45})O_3$ (PZT) bimorph actuator coupled to a wing hinge that mechanically amplifies the bend action of the bimorph, which is then transferred to the wing as shown in figure 1. An important aspect of insect-like flapping motion is the amplitude of the wing motion. A non-contact physical measurement solution is sought to record the movements of the wing and bimorph in order to explore the full capacity of the device. The peak-to-peak displacements of both the actuator and the wing amplitude was measured using a MTI-2100 Fotonic [1] Sensor manufactured from MTI instruments.

Figure 1. MTI-2100 Fotonic Sensor instruments.

The MTI-2100 is a measurement system that provides for non-contact precise measurement of the position, the displacement (micro-positioning), and the vibration of an object in planar motion. These measurements provide assistance to thoroughly understanding the structural dynamics of a planar actuating object. The MTI-2100 has a dual-channel photonic sensor controller that has a RS-232 interface port, displacement analog outputs, automatic calibration buttons, and a digital display of the probe gap/displacement. The dual channels offer two options to switch between two different types of photonic sensor probes (this concept will be

[1] Fotonic is a trademark of MTI Instruments Inc.

addressed in the next paragraph). The RS-232 interface port provides data communications output for data acquisitions, which is only available on one channel at a time, since the circuitry can only monitor one channel at a time. The displacement analog output is located on the rear panel of the MTI-2100 system where a Bayonet Neill-Concelman (BNC) jack (BNC connector) is provided for each channel. The analog voltage displacement signal converts the voltage to engineering units, which is given in microns (µm) per millivolt (mV), as shown on the display. The automatic calibration step is the first step required once the instrument is turned on (this topic will be addressed in greater detail later in section 3 of this report). Lastly, the digital display shows calibration, displacement, or voltage; these options can be manually switched by the user with the mode knob in the upper right hand corner of the instrument.

Along with the controller, there are two plug-in probe modules that have high/low pass band filters to filter the noise out of the signal. MTI Instruments offer standard probes modules that are designed for making displacement measurements on the range from <0.025 µm/mV to >1 µm/mV. They also offer high resolution probe modules that are designed for making displacement measurements on the range of 0.005 µm/mV (Range 1). Furthermore, as shown in figure 2, inside the probe there are two adjacent fiber optic elements, whereas one is a light transmitting fiber and the other is a light-receiving fiber that sends the signal to a photo detector to capture the maximum amount of reflected light relative to the amount of source intensity. This signal is decoded as an output vs. distance signal response with a digital output translating the data into a displacement reading.

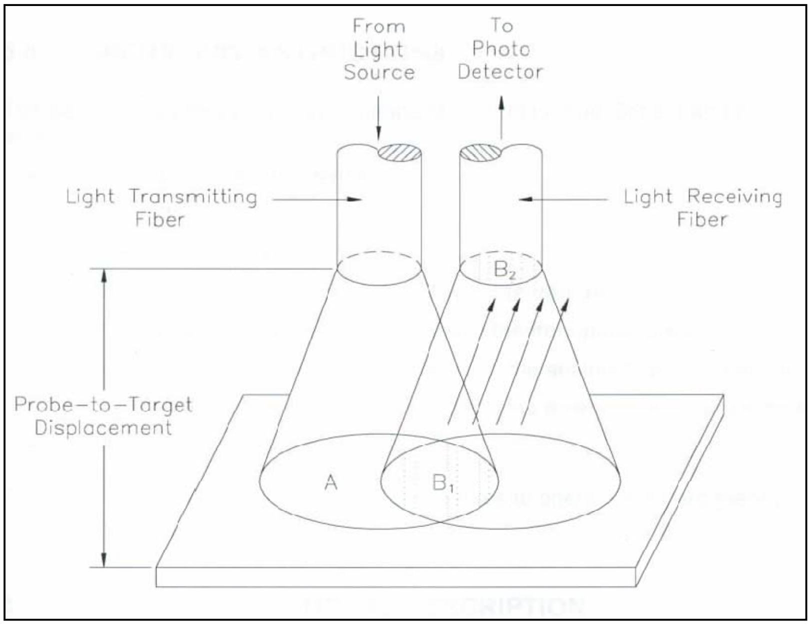

Figure 2. Displacement sensing mechanism of adjacent fiber-optic elements.[2]

[2] *User Manual MTI-2100 Fotonic™ Sensor*. Document ID: A0697; MTI Instruments, Inc: Albany, N.Y.

The basis of operation is the interaction between the field of illumination of the transmitting, and the field-of-view of the receiving or detector fibers, such that at contact/zero gap (zero distance between the probe and the reflective surface of the end of the actuator) the light exiting the transmitting fiber is reflected directly back into the same fiber not allowing enough light into the receiving fiber wherein produces a zero output signal to the photo detector. As the distance increases between the probe and the actuator surface, a diverging field of reflected light will exceed the field-of-view causing the receiving fiber to register an output-versus distance signal response.

2. Noise

A small amount of noise is produced in the MTI-2100 Fotonic Sensor by the probes modules' current to voltage circuitry. The reflected light detected by a light receiver is a photodiode that converts a small current into a voltage signal, which is then sent through a low pass filter (noise reduction will increase the measurement accuracy). For the low pass filter switch, the lowest and highest cut-off frequency is 100 Hz and 100 kHz respectively. Since noise reduction will increase the accuracy of the measurements, the low pass filter switch is used to reduce high-frequency noise. The high pass filter is ideal to block out low-frequency vibration (e.g., fixture seismic vibration or building vibrations) during the testing. The high pass filter range is from 20 Hz to 200 Hz.

In order to measure from a reflective surface, MTI recommends that a Scotch [3] brand polyester film tape No. 850 reflective surface should be used in order to adequately reflect the light. Once the machine is turned on, the user must select to operate under either channel one or channel two. This option depends on the type of modules inserted into the instrument (see figure 1). The user must analyze the measurement requirements before selecting the appropriate probe module. For example, in this experiment the standard probe module occupied the channel one slot.

The user should select the module based on the anticipated estimation of displacement range of the target. The MTI-2100 probe module has an option to switch from "Range 1", which is programmed to accept high resolution measurements to "Range 2", which is of a lower resolution setting or a larger range of movement. Range 1 is generally for actuators displacing from 0.1- to 1.7-mm range, whereas Range 2 is set for actuators ranging from 1.7- to 4.4-mm displacement. It is important to set the appropriate range, which will set the scaling factor that is applied to the probe module output voltage and converting the output voltage into a scaled voltage.

[3] Scotch is a trademark of 3M.

3. Calibration Procedure

First select the calibrate button, and make sure the light source is on. The probe must be parallel to the target. The probe should contact the target (at this point the reflective tape should be on the target) and then back the probe off in a perpendicular fashion slowly until an optimal peak of 200 mV is reached. For a second time, the user should move the probe perpendicular to the surface to locate the center point. This is done by moving the probe upwards until the maximum voltage is reached (i.e., usually 2.5–4.2V). Then press the calibrate button ("CAL START"). Once the instrument has calibrated, the display should read between 10.000 V (±75 mV) then the calibration cycle is complete. If you do not get a reading within this range, it is highly recommend that you redo the calibration procedure, because there may be insufficient light being reflected from the target surface. Also, it is not necessary to recalibrate the instrument every time it is turned on. It is only necessary when the target surface has changed, moved to a new area over the target, or when the probes modules are interchanged.

4. Displacement Operation

When the calibration procedure is complete, turn the knob to displacement and begin running the experiment (i.e., activate the target/actuator). If an over or under range LED light is enabled, then there will be an error in the displacement measurements. The LEDs indicate that the target is out of range.

If the user needs to determine the distance between two points for his/her experiments, the user should record the initial reading on the display and then move the target to the second point and then record the second reading, the difference between the two readings is the total displacement of target surface. The Auto Zero feature can also be used to observe displacements measurements on the display between multiple points. For example, in the event the operator wants to reposition the probe, the Auto Zero feature can be used to directly measure the distance that the probe has moved. The user should press the Auto Zero button located on the bottom front panel, and this option is available to zero out previous values.

On the rear panel analog output BNC jack is used to interface with an oscilloscope or a data acquisition system. The analog displacement signal must be converted to engineering units (μm/mV) using the calibration curve as shown in figure 3. Every probe has a different slope factor, and the user must apply the slope factor that corresponds to specific range that is currently in use (see figure 3).

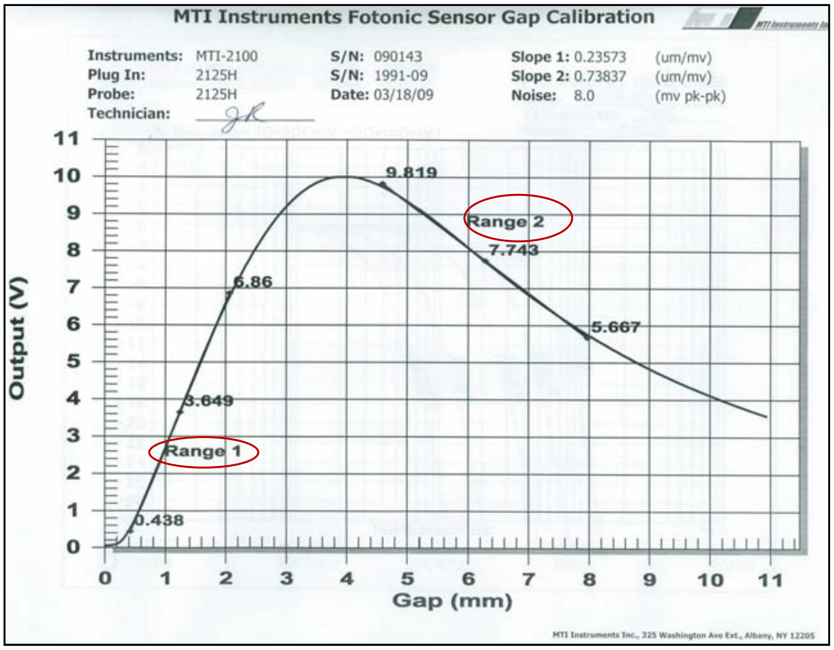

Figure 3. This graph displays the calibration curve for the standard probe 2125 H with both Ranges 1 and 2 identified.[4]

In order to receive a displacement measurement from an analog signal, the user must convert the analog voltage signal by multiplying the calibration curve point by the output voltage signal (see equation 1 below).

$$\text{Displacement} = \text{Range Slope Factor } (\mu\text{m/mV}) \times \text{Output signal (mV)} \qquad (1)$$

5. Experimental Results

Figure 4 shows the displacement as a function of frequency for an insect-like flapping wing design. The dimensions of the bimorph actuator that drives the wing motion is 3.6 cm in length, 0.65 cm in width, and 0.075 cm in thickness, and it should be noted in figure 5 that a 22-µm-thick low density polyethylene wing material displayed the highest flapping amplitude of 11 mm at a system resonance frequency of 13 Hz operating under 60 V_{pp} across the bimorph. The synchronization of the spar motion, the bimorph amplification scheme, and the mechanical transmission element mandates the flapping amplitude.

[4] MTI Instruments, p. 2. (Referring to the work fully identified in an earlier note.)

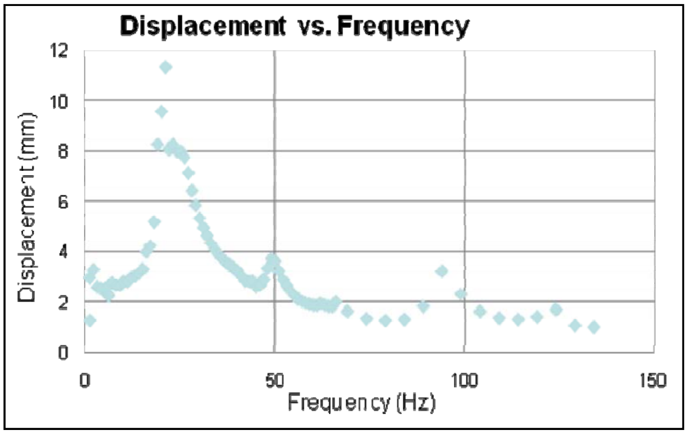

Figure 4. This graph displays displacement as a function of frequency. The displacement was measure at 60 V_{pp}.

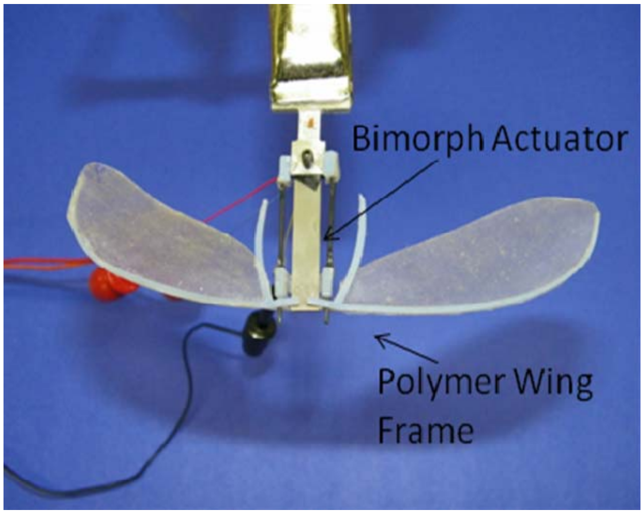

Figure 5. Insect-like flapping wing bimorph actuator and wing frame.

6. Conclusion

This report describes the operational principles of the MTI-2100 Fotonic Sensor measurement system. To illustrate how it works in practice, the measurement system was used on a PZT bimorph-driven flapping wing to measure flapping amplitude and frequencies. Overall, the report is intended to serve as a guide especially suited for PZT-type measurements.

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